Summary Information Page

i. Funding Opportunity Number and Title: EPA-R5-GL2012-2
Great Lakes Long-Term Biological Monitoring of Zooplankton, Benthos, and Chlorophyll *a*

ii. Project Title: Great Lakes Long-term Biological Monitoring Program

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iv. Type of Organization: College and University

v. Proposed Funding Request: $3,867,525

vi. Project Duration Period: October 1, 2012- September 30, 2017.

vii. Brief Project Description

The EPA Monitoring Program is designed to provide managers access to biological data on zooplankton and benthos to support decision-making. This project will collect zooplankton, benthos and chlorophyll data across the five Great Lakes from 2013 to 2017, analyze this data and make it available to environmental and fisheries managers. Four additional research projects includes studies of the deep chlorophyll layer, comparative ecology of mysids, evaluation of early detection system for invasives, and evaluation of biotic indices of ecosystem health. The project will be conducted in association with Cooperative Science and Monitoring Initiative years in each of the Great Lakes.

Work Plan

i. Project Summary and Approach

The EPA Biological Monitoring Program (EPA-BMP) is designed to provide managers and scientists across the Great Lakes access to biological data on zooplankton and benthos to support environmental decision-making and as background for various research projects. This is the main goal of work proposed here. In addition, we propose four research projects that we believe will improve the existing monitoring program, inform environmental and fisheries management, and lead to better coordination with other actors in the region (USGS, NOAA, USFWS, state agencies, and Canadian federal and provincial agencies). These research projects will use the EPA-BMP data as well as additional data that we propose should be collected during Cooperative Science and Monitoring Initiative (CSMI) years in each of the Great Lakes. The proposal builds on our involvement with lower trophic assessment in Lake Ontario in 2003 and 2008, in the planning phase for CSMI 2013 in Lake Ontario, and similar assessments in Lake Erie in 2009 and 2011-2012 (Lake Erie nearshore-offshore nutrient projects NOLENS and LENONS funded by EPA GLRI).

1) Sample Collection

Samples will be collected on the R/V Peter Wise Lake Guardian during the annual surveys of the Great Lakes in April and August beginning in 2013 through 2017. Well in advance of each cruise we will submit sampling plans to the captain that specifies sampling activities and monitoring stations. This plan will include information on crew rotations and berth needs. Our sampling group (five members, three on watch at any particular time) will travel via van to Milwaukee, Wisconsin to board the ship to begin sampling in Lake Michigan. After sampling Lake Michigan, Huron, Erie, and Ontario we will use a port close to our base (Rochester or Fort Niagara) to rotate personnel and equipment. The sampling group will then travel on the boat to Lake Superior to complete sampling. Our group will then offload with equipment and samples at a convenient port along the ship's route (Detroit, Cleveland, or Fort Niagara). Any changes in personnel or berth needs during the cruise will be quickly relayed to the captain.

Each station will begin with a Seabird rosette cast for water column profiling and collection. One of our groups will collect water from each Niskin bottle for chlorophyll *a*. They will coordinate with other rosette samplers including water chemistry and phytoplankton samplers. When the rosette is secure on deck, two other science personnel on the fantail will conduct two zooplankton net hauls and three Ponar grabs. They will be assisted by the science watch officer and a winch operator. The sediment samples will be elutriated and the zooplankton and benthic invertebrate samples will be preserved following EPA SOPs. A secchi disk will be done for all daytime stations. Additional QA/QC activities (such as replicates (10% of total samples) or flowmeter calibrations) will be included when appropriate. Data sheets will be maintained with station information and flowmeter measurements. Safety regulations will be followed including close communication with the crew, wearing hardhats, close-toed shoes, and work vests, and the use of fume hoods during sample preservation. Efficient but careful and thorough sample collection will be our constant goal.

Chlorophyll *a* sample processing will follow EPA Standard Operating Procedure (SOP) LG 404 (Revision 6, 2002). Water samples will be filtered at low pressure (< 5 psi) under subdued light within two hours of collection. A filtration manifold set up for 47 mm diameter GF/F filters will be used. For productive Lake Erie 150 ml will be filtered but for the other less productive lakes the amount will be 250 ml. The volume will be measured using a well-rinsed graduated cylinder after inverting the sample bottle to mix uniformly. With a small amount of filtrate left in the funnel, ten drops of $MgCO_3$ solution will be added. At the end of filtration the sides of the funnel will be rinsed with reagent water and the vacuum

pressure released. The filter will be carefully folded and put in a culture tube and the completed rack will be wrapped in aluminum foil and stored frozen.

EPA SOPs will also be followed carefully for collection of zooplankton (LG402, Revision 10, 2005) and benthos (LG406, Revision 7, 2002). We will supply the zooplankton nets and have back-ups on hand. A surface (0-20 m, 63 um) and whole water column (0-100 m, 153 um) zooplankton tow will be done at each station carefully recording flow-meter information. In cases where the site depth is less than the tow depth the sample will be collected from 2 m above the bottom. Nets will be rinsed to concentrate material in the sample bucket. Excess water will be removed prior to transferring to the sample bottle. The zooplankton will then be narcotized with soda water and preserved in a sugar formalin solution. Sediment samples will be collected using the Ponar of the Lake Guardian generally during the summer survey. We will use their elutriator to gently rinse to concentrate benthic invertebrates in a mesh sleeve and the affixed sample bottle. Benthic samples will be preserved in a 5-10% formalin solution with Rose Bengal stain. A fourth substrate characterization sample will be collected and frozen in two bottles (500 ml for organic content, 1 L for grain size). We will provide all sample bottles and preservative and use preprinted labels provided by EPA.

2) Sample Analysis

Our group will be responsible for the analysis of all samples collected during the spring and summer of 2012 through 2016. We will coordinate with the EPA to receive the zooplankton and chlorophyll *a* samples at the Cornell Biological Field Station in Bridgeport, New York (CBFS). Benthos samples will be shipped to our collaborators at Buffalo State College in Buffalo, New York. Our plan is to process all 2012 samples prior to the spring survey in April 2013. Subsequent years' sample will be processed prior the April sampling cruise.

To ensure continuity and consistency in taxonomic identification we will hold two workshops during fall of 2012, one for zooplankton and one for benthos. We will invite zooplankton and benthic scientists interested in the Great Lakes. These workshops will be led by Rudstam (zooplankton) and Burlakova (benthos) and held at the CBFS. CBFS can provide microscopes, classrooms, and lodging. We will use $2000 of our first year extension travel budget to support these workshops and provide food and lodging for up to 10 participants.

Chl-*a* samples (approximately 1150 samples per year) will be analyzed with a calibrated Turner Designs 10-AU bench-top fluorometer following EPA SOP LG 405 (2004, Revision 7) either on board of the Lake Guardian or at CBFS. This will be done by one of the technicians trained in the technique and under the supervision of Dr Watkins. Filters should ideally be run within 3 ½ weeks of collection. A set of filters will be extracted in buffered acetone in a -20 C freezer for 16-24 hours after sonication. Once samples reach room temperature each one will be mixed and filtered through a GF/F filter into a culture tube. After blank and solid standards are run individual samples will be analyzed for chl *a* in a glass cuvette.

Zooplankton samples will be processed following LG 403 (2003, Revision 3) at CBFS. CBFS is well equipped with two counting stations for zooplankton identification and computerized measuring system. We have been counting and measuring zooplankton from Lake Ontario since the 1980s and from other lakes since 1968. Current employees have 6 ([redacted]) and 4 ([redacted]) years of experience counting Great Lakes zooplankton for the New York/Cornell Biomonitoring Program. Large predatory cladocerans (*Cercopagis* and *Bythotrephes*) and *Mysis* will be separated from the main sample and counted separately. The main sample will be split using a Folsom splitter. The goal is to count between 200 and 400 organisms (not including nauplii) for each subsample and to measure the first 20 animals in each species and life stage. In addition to the two final split samples with this number of organisms (referred to as subsamples A and B), one sample equal to the sum of these two (subsample C)

will be used to enumerate subdominant taxa where less than 40 individuals were counted in both A and B. A fourth subsample (D) equal to the sum of the three previous subsamples will be examined for large and rare taxa. Microcrustaceans will be identified, counted and measured for length using a dissecting scope. For the 63 um surface tow only, smaller organisms (rotifers, copepod nauplii, and dreissenid veliger larvae) will be counted and measured within two 1 ml subsamples from an appropriate split using a Sedgewick-Rafter cell and a compound microscope at 100x magnification. Each subsample should contain between 200 and 400 rotifers and nauplii. These smaller animals will be measured with a computerized tablet connected to the compound scope. We will follow the naming conventions within the SOP and calculate biomass for each individual using the length-weight relationships included. Overall density and biomass will be calculated using flow-meter and split information. Consistency between different analysts will be ensured following steps outlined within the SOP. Ten percent of the samples will be analyzed by two analysts and similarity assessed. The two counts should be within 90% of each other when applied to the same subsample.

Benthic samples will be processed following LG 407 (2010, Revision 7) at Buffalo State College in Buffalo, New York by the group of [redacted] and [redacted] Dreissenid mussels will be separated out, identified by species (*Dreissena polymorpha* or *Dreissena rostriformis bugensis*) and measured for length in 5 mm bins. A Folsom splitter will be used for subsampling if the number of dreissenids is more than 200 individuals. Other major taxonomic groups (amphipods, chironomids, oligochaetes, mollusks) will be sorted into individual scintillation vials and later identified following the naming conventions outlined in the SOP. Chironomids and oligochaetes will be mounted on slides that will be archived. In addition to the standard procedure we will measure the total wet biomass of every species of benthic macroinvertebrates in each sample. Organisms in vials will be archived in 70-80% ethanol with 5% glycerin to avoid dessication. The vials for each sample will be put in a larger jar with ethanol. Spent sediments will be saved until quality control checks have been conducted. Numbers will be converted to per m^2 using the conversion 19.12 based on the dimensions of the Ponar sampler.

3) Data management

On the Lake Guardian, field collection sheets will be written on water resistant paper and scanned on board each day. This information will be checked daily for consistency with sample bottle labels. Site information and flowmeter data will be transferred to an Excel spreadsheet that includes equations to calculate volume of water filtered in each net. A separate chlorophyll spreadsheet will include site information, Niskin bottle depth, and volume of water filtered. As information is added, backups of these files will be saved to an external hard drive and hard copies kept.

In the laboratory during chl *a* analysis, fluorometer readings for each sample will be recorded with label information as well as blanks and solid standard readings. This data will be transferred to a spreadsheet to calculate chl *a* in ug/L using an equation that includes volume of water filtered. Hard copies will be made after analysis and spreadsheets with data from each run will be backed up on an external hard drive.

Each zooplankton count will be entered to a separate Excel spreadsheet that includes sample label information, volume filtered, split information, and subsample type. We will follow species naming conventions and length-weight (L-W) coefficients outlined in the EPA SOP. Our microscope counting stations are connected to a digitizing tablet that automatically transfers individual length measurements to columns for selected species within an Excel spreadsheet. All counts and at least 20 length measurements per species or life stage will be entered into an Excel spreadsheet for calculation of average size. Density of each species or life stage will be calculated using count data and volume filtered and split information using the equation described in the SOP. Biomass will be calculated using the geometric mean length of each species or life stage and L-W coefficients provided within the SOP.

Zooplankton counts will also be compiled within a relational Microsoft Access database that has a sample table (with site, flow meter and split information) linked to tables of individual counts/lengths and a taxonomic table with length-weight coefficients. We have assembled such databases for organizing the data of a fifteen-year zooplankton sampling program for Lake Ontario. One advantage of such a system is that we can recalculate biomass using different sets of L-W weight coefficients used by other researchers in the region (see dataset in Rudstam, Luckey and Koops http://knb.ecoinformatics.org/knb/metacat/jimont.133.3/knb). This flexibility is important for comparing our results to those of other programs. For each sample, the density and biomass for each species (using EPA L-W coefficients) will also be compiled in a form compatible with that of the EPA GLENDA database. All files (individual counts and databases) will be backed up to an external hard drive.

Off site data backup will use the Cornell Box, a program that offer off-site storage with frequent backup procedures for securing electronic data. All biomonitoring-related files will be set up to backup automatically each day to this site.

Benthos analysis will follow a similar plan with individual count data within separate Excel files for each sample that includes calculation of density (in individuals per m^2) and biomass (in g per m^2). These counts will then be compiled into a relational Access database following taxonomic naming conventions outlined in the SOP and data formats compatible with the EPA GLENDA database.

4) Data interpretation, statistical analysis, and report writing

We intend to take an active role in the interpretation of the generated data within the context of long-term trends. In our past work on Lake Ontario, we have interpreted trends using the combined results of different data series, including the EPA-BMP, the Bioindex Program of Department of Fisheries and Oceans – Canada (DFO), the surveillance program of Environment-Canada (EC) and the Biomonitoring Program of New York State Department of Environmental Conservation (NYSDEC), USGS, USFWS and Cornell University (Mills et al. 2003, Hall et al. 2003, Holeck et al. 2008, Watkins et al. 2007, Holeck et al. 2012, Rudstam et al. in review). This approach has been possible by timely dissemination and sharing of data sharing among the collaborating agencies in the US and Canada. If awarded this grant, we intend to participate and, if needed, facilitate such collaborative arrangements across the Great Lakes.

The combination of data series also requires inter-calibrations of analytical methods and comparisons of equations used for calculations of derived measures. For example, zooplankton biomass is based on measures of length-weight regressions. The regressions used vary among groups including for example the federal agencies in the US (EPA) and Canada (DFO). We have recently reviewed these equations and found some errors and poorly defined relationships used in both sets of equations (Watkins et al. 2011). We will work towards adopting the same equations throughout the basin and across agencies, but before this happens we will provide biomass estimates using three sets of equations (EPA, DFO and proposed new standards, see Rudstam et al. 2012). This is important as the interpretation of time trends in zooplankton biomass is different depending on the regressions used, at least in Lake Ontario. Another example is units used for Si concentrations varies over time and across agencies (measures in SiO_2 by Environment Canada and Si by EPA). As part of the work proposed here, we will deal specifically with inter-calibration of chlorophyll through comparisons of methods (fluorometer, spectrophotometer, total chlorophyll measures, tri-chromatic measures, phaeopigment corrections etc.) by comparing these methods using additional samples collected during the EPA-BMP program.

Statistical analysis of time trends has to deal with auto-correlation among years. We have used time series analysis (intervention analysis) in the past for analyzing effects of fish and mussels on zooplankton and benthos in smaller lakes (Rudstam et al. 1993, Mayer et al. 2000, 2002) and change point analysis (Taylor 2003) for determining breaks in the time trends of lower trophic levels in Lake Ontario (Holeck et

al. 2012). We will pursue appropriate time series approaches for trend analyses in the EPA-BMP data after consultations with statistical expertise at Cornell University.

Understanding time trends also requires understanding spatial patterns. Satellite data helps expand the more limited ship board data both in space and time. We have used satellite data to help interpretation of ship-based data (Watkins 2009, 2010, Watkins et al. submitted, Rudstam et al. in review). We are interested in fostering further collaborations with remote sensing groups including groups at EPA and Michigan Tech, as well as international groups (current collaboration between CBFS and Water Insight B.V, the Netherlands associated with Lake Ontario sampling in 2013). We see potential steps in coordinating this time series with other ship-based lower food web sampling programs as well as buoy/remote sensing and fishery data sets. Expertise in spatial analysis is available at Cornell University and Rudstam has a long-term working relationship with [redacted] an expert on spatial statistics in the Department of Natural Resources. [redacted] and [redacted] collaborate on several projects using geostatistics to estimate uncertainty in acoustic estimates and similar approaches will be employed to interpret data collected by the EPA-BMP program. Spatial analysis is part of two of the proposed research projects (see below).

Reports will be produced each year that summarize the findings from all the Great Lakes with special attention to comparisons among these lakes. Recent work on comparisons among Lakes Huron, Michigan and Superior described interesting trajectories of the zooplankton communities in the three lakes, with Huron and Michigan becoming more similar to Lake Superior (Barbiero et al. 2012). This analysis was based on multidimensional scaling of community abundance matrices, an appropriate technique for ecological data. We will also apply nonparametric multivariate methods to analyze community structure among lake zones and habitats within each lake, among lakes, and compare to previous data. The proposed addition of recording wet benthic biomass to standard sorting procedure will allow us to extract more information from the same samples and allow more dimensions and power to our analysis. This approach was successfully applied to analyze long-term data of benthic community of Lake Mendota, Wisconsin, and has been proved to differentiate between long-term change and natural spatiotemporal variation in community structure (Karatayev et al. 2012). We will explore these approaches and other multivariate methods to help interpret changes in the Great Lakes.

We have closely followed the scientific literature based in part on EPA GLNPO data including papers written by lead author [redacted] These papers are often excellent and we would be pleased to collaborate with [redacted] in the analyses of the 2012-2016 data sets. In any case, we are enthusiastic to analyze the survey data time series and publish papers that can inform managers and the public on the current status of the Great Lakes.

5) Research

We propose four research projects to complement the EPA-BMP. Project 1 on the importance of the deep chlorophyll layer is intended to add to the CSMI sampling in 2013 in Lake Ontario and beyond to the other Great Lakes. Project 2 on comparative ecology of *Mysis diluviana* is in response to the increasing interest in this component of the Great Lakes food web. This project would also develop a standard operating procedure for monitoring mysids using high frequency hydroacoustics. Project 3 on the early detection of invasive species takes a world-wide approach to identifying potential invaders and disseminating information about these organisms for potential use in eDNA analyses. Project 4 is looking at the benthic indicators used to date by EPA as mussels have changed the benthic environment and potentially affecting the reliability of these indices. Although we do not directly address the stated need for collaboration on research using the LOPC data for nearshore zooplankton monitoring, we are interested in using the LOPC during the CSMI years in each of the Great Lakes in conjunction with

Project 1. The analyses of these data will hopefully help with the interpretation of LOPC data also in the nearshore.

Project 1: Comparative analysis of the deep chlorophyll layer (DCL) and associated zooplankton across the Great Lakes (Ph.D. student at Cornell University, [redacted] at USGS-LOBS).

Lake Huron, Lake Michigan and in particular Lake Ontario are undergoing a vertical re-structuring of the food web. We hypothesize that primary production is increasingly occurring in the deep chlorophyll layer (DCL). Deep chlorophyll layers are seasonally important in deep oligotrophic lakes (Abbott et al. 1984, Pilati and Wurtsbaugh 2003) including the Great Lakes (Moll et al. 1984, Barbiero and Tuchman 2001, Twiss et al. 2012). In Lake Michigan, 30 to 60% of the areal primary production has been attributed to the DCL (Moll et al. 1984, Fahnenstiel and Scavia 1987). There are several non-exclusive hypotheses for why DCLs are formed. Higher nutrient availability in the metalimnion would increase algal growth rates at these depths. Grazing may be lower in the metalimnion if more zooplankton resides in the warmer epilimnion. The DCL may not equate to higher algal biomass due to higher chlorophyll content in dark-adapted algae (Pilati and Wurtsbaugh 2003, Reynolds 2006). In addition, productivity in the DCL may be lower per unit algal biomass or unit chlorophyll than in the epilimnion due to light limitation. Still, it appears that the increasing water clarity has resulted in a re-organization of the Lake Ontario offshore ecosystem towards one with substantial production, potentially over 50%, in deeper water (Weidel et al. in prep). The proportion of production in deep water may be even higher in the upper lakes. Thus, we cannot understand productivity in these lakes without attention to the DCL.

We also expect that production in the DCL is increasingly important for secondary production including microzooplankton (Twiss et al. 2012a), zooplankton, mysids, and fish. Zooplankton species that dominated in 2008 in Lake Ontario (*Limnocalanus macrurus* and *Leptodiaptomus sicilis*) are large calanoid copepods that prefer colder water and are found in the DCL. *Limnocalanus* is increasing also in lakes Michigan and Huron (Barbiero et al. 2012). Further, mysids that make up a 15% of the crustacean biomass in Lake Ontario (Rudstam et al. in review) prefer temperatures around 7 °C and often concentrate in the metalimnion and lower hypolimnion (Boscarino et al. 2009). Mysids would likely benefit from feeding in the DCL (see below project 2). The shift of zooplankton biomass to cool water habitats also has important implications for bioenergetics of organisms and the restoration of native fish such as deepwater coregonids. Our objectives are:

1) To predict the magnitude, composition, productivity and depth of the DCL based on the variables temperature, light (PAR), and season.
2) To investigate the use of the DCL by crustacean zooplankton. We hypothesize that the production in the DCL is an important source of nutrition for zooplankton and also affects their vertical distribution.
3) To predict the growth response of current and extirpated coregonids (cisco, kiyi and bloater), alewife, and rainbow smelt to the vertical restructuring of the Lake Ontario food web. We hypothesize that potential production by native coregonids is higher than potential production by alewife in the restructured Lake Ontario. This information is needed to guide future fisheries management actions.

With this proposal, we are seeking support for a Ph.D. student and a couple of months of technician time for this project associated with the CSMI in Lake Ontario in 2013 and to apply the methods developed in Lake Ontario to each of the other Great Lakes associated with CSMI activities (Lake Erie in 2014, Lake Michigan in 2015, Lake Superior in 2016 and Lake Huron in 2017). Additional support is through in-kind support from USGS-GLSC and OMNR for 2013 in Lake Ontario. Methods will be modified for the other lakes following our analyses for the Lake Ontario project and are described briefly below.

1) To predict the magnitude, composition, productivity and depth of the DCL based on the variables temperature, light (PAR), and season. Depth profiles of temperature, oxygen, light (PAR) and

chlorophyll will be collected for all stations sampled during the 2013 Field Year in Lake Ontario. In addition, samples will be collected from the epilimnion and the DCL for analysis of algal composition using a Van Dorn sampler or the Rosette sampler available on the R/V Lake Guardian. Depth of the discrete-depth algae samples will be determined based on the fluorescence profile. We will use one month of technician time from this proposal for measuring algal biomass and composition of 40 DCL samples in each year. We will use these data to obtain basic information about the DCL in Lake Ontario. This includes the correlation between chlorophyll concentrations in the DCL and the variables depth, temperature, and light, as well as the seasonal changes in these correlations.

We will estimate pelagic primary production by measuring changes in diel, free water, dissolved oxygen concentration with automated sensors, meteorological variables including photosynthetically active radiation, wind speed, and a modified Odum model (Odum 1956, Cole et al. 2000, Staehr et al. 2010). This technique, that allows estimation of both primary production and respiration, is not biased by container effects or issues of scale, common critiques of primary production methods that incubate bottles of lake water or radioactive ^{14}C. Optical oxygen probes, which continuously record ambient dissolved oxygen and temperature, will be fixed at four depths via a moored buoy and collect information over a period of 12 days. Photosynthetically active radiation (PAR) will be obtained from shore or lake based metrological stations and wind speed data will be downloaded from NOAA buoys. Calculations for gross primary production (GPP) and respiration (R) will follow methods outlined in Staehr et al. (2010). Primary production in DCL will be compared with epilimnetic production as well as historical production data (e.g. Millard et al. 2003).

2) To investigate the use of the DCL by crustacean zooplankton. Zooplankton will be sampled at each station with a 0.5 m diameter, 153 μm, metered closing net following EPA procedures described above. Samples with the closing net will be divided in at least 3 depth layers - above, through, and below the DCL. Standard sampling (100 m to surface with a 0.5 m diameter 153 μm net and thermocline to surface with a 0.5 m diameter 64 μm net) will also be completed at each station. We also expect to use high frequency acoustics (430kHz) to estimate the zooplankton distribution in more detail (see Figure 1). We expect the dominant species in the DCL to be large calanoids (*Limnocalanus macrurus* and *Leptodiaptomus sicilis*), but *Daphnia mendotae* may also be abundant. We will use light, temperature, chlorophyll concentrations, and zooplankton species composition as variables in a general additive model (GAM) of vertical distribution of acoustically derived zooplankton abundance. Models of different complexity will be compared with an information criteria index (AIC or BIC) to investigate the importance of the DCL for determining zooplankton distribution and abundance in Lake Ontario. We recently used this approach to predict distributions in Lake Champlain (Simonin et al. 2012).

3) To predict the growth response of current and extirpated coregonids (cisco, kiyi and bloater), alewife, and rainbow smelt to the vertical restructuring of the Lake Ontario food web. Fish growth depends on food density, the ability of the fish to detect and capture food, and the different physiologies of the fish species. Bioenergetics models are used to relate growth and consumption based on a mass balance approach (Kitchell 1983). Such models were developed for Great Lakes forage for alewife (Stewart and Binkowski 1986), rainbow smelt (Lantry and Stewart 1993), and bloater (Rudstam et al. 1994) in the 1980s and 1990s. Since then, several investigators have updated the information for coregonids and clupeids (e.g. Klumb et al. 2003, Madenjian et al. 2006, Mehner et al. 2011) and we will consider this information to update the Great Lakes forage fish models.

Food consumption will be predicted from functional response models with light, temperature and food availability as input functions (Wright and O'Brien 1984; Mason and Patrick 1993; Jensen et al. 2006). There are many examples, including applications for salmonids (Stockwell and Johnson 1997, Ahrenstorff et al. 2011) and clupeids (Jensen et al. 2011). Food consumption will decline with declining light because the potential forage fish we are interested in are visual predators (at least when feeding on

larger particles, Janssen 1978, Boscarino et al. 2010) and food encounter can be predicted based on reactive distance and swimming speed (Gerritsen and Strickler 1977). We will use available information in the literature to construct a plausible model of food consumption for these species as a function of light, temperature and prey concentrations. The combined bioenergetics/functional response model will be used to explore the effect of the distribution of zooplankton and mysids associated with the DCL on the growth potential of alewife, rainbow smelt and coregonids. Sensitivity analysis will be used to investigate the effects of different parameters on the growth potential of different species. We expect that the forage fish growth potential will be higher for coregonids in the lower temperatures of the DCL than for alewife. These calculations would help estimating the potential for reintroduction of deepwater coregonids in Lake Ontario.

This project is intended to be part of the CSMI activities in 2013 in Lake Ontario. Cornell University is heavily involved with the planning process for these activities; both associated with current GLRI grant and associated with long-term collaborations with NYSDEC, OMNR, and USGS and DFO-Canada. We plan on continuing this work in the other four Great Lakes building on our experiences in Lake Ontario in 2013.

Project 2. Comparative Ecology of Mysis diluviana in the Laurentian Great Lakes (Ph.D. student at Cornell University, [redacted] collaborators across the Great Lakes basin)

Mysids are omnivores and a major component of the Great Lakes food web in Lakes Superior, Michigan, Huron and Ontario. In Lake Ontario, mysids are the main zooplanktivore in the offshore, consuming more zooplankton than are consumed by fish (Gal et al. 2006). Mysids are also important for benthic-pelagic coupling. Mysids, not fish, may be the most important predator on *Diporeia* in both Lake Ontario (Stewart and Sprules 2010) and Lake Superior (Sierszen et al. 2012). Although most recent research on mysid ecology in the Great Lakes is from Lake Ontario (collaborations between Ora Johannsson from DFO and PI Rudstam and his students, see reviews by Johannsson et al. 2003 and Rudstam and Johannsson 2009), there is an increasing realization of the importance of this species across the basin and consequently, an increasing interest in mysid research (Isaac et al. 2012, Sierszen et al. 2012, Bunnell et al. 2011). With the decline in *Diporeia* in most of the lakes, mysids are also becoming a more important prey item for benthic fish (Owens and Dittman 2003). Clearly, we need a better understanding of the role of mysids in these food webs and a better method for monitoring this important species. Sampling mysids requires dedicated effort at night because mysids are in the water column at night when they migrate to the lower metalimnion to feed on zooplankton and algae and because they are able to avoid bottom grabs used for benthic sampling during the day.

We therefore propose a research project on the comparative ecology of *Mysis diluviana* (formerly *Mysis relicta*) across the Great Lakes as part of this proposal. We hypothesize that the importance of mysids in the four deep lakes is higher in lakes without native fish specializing in feeding on mysids. Further, we hypothesize that the importance of mysids will increase if the production in the DCM increases (Project 1). The effect of mysids will be depth dependent, both because mysids tend to be more abundant in water deeper than 100 m, and because mysids avoid the warmer epilimnetic water. Therefore, we also need to predict their vertical distribution and compare this with the distribution of zooplankton and algae obtained within the DCL project described above. To investigate the role of mysids in the Great Lakes food web, we need estimates of mysid abundance, distribution, diet, and growth rates and compare mysid consumption with that of fish. Therefore we will also develop the monitoring program needed to assess mysid abundance across the Great Lakes. We propose that this is done with dual frequency hydroacoustics (120 and 430 kHz). We are already collaborating on fish acoustic surveys across the Great Lakes with the USGS Great Lakes Science Centers in Ann Arbor, Oswego, Sandusky and Ashland as well as with Ontario Ministry of Natural Resources (OMNR) and New York Department of Environmental Conservation (NY DEC) offices for Lakes Erie and Ontario. More recently, we are

working with USGS GLSC to better define methods for acoustic estimates of mysids ([redacted]). We therefore envision this project to be based on collaboration between the USGS Great Lakes Science Centers across all the Great Lakes and the EPA biological monitoring program. Specifically we propose to:

1) Test hydro-acoustic methods to estimate mysid abundance across the Great Lakes.
2) Compare mysid abundance, growth rate and condition across the four deep Great Lakes.
3) Evaluate mysid diets through stomach analyses, stable isotopes, and genetic markers.
4) Compare vertical distribution of mysid in the different lakes with predictions from a model relating distribution to light and temperature gradients.
5) Evaluate the importance of mysids in the food web of each of the four deep Great Lakes and compare this with fish zooplanktivory.

Methods.

1) Test of hydroacoustics methods for mysid abundance. High frequency acoustics have been used for zooplankton studies in both marine and freshwater systems for a couple of decades (Smith et al. 1992, Foote and Stanton 2000), but not yet as a standard method for Great Lakes mysids. Mysid migrations are obvious at a range of frequencies and have been studied with 120 and 430 kHz in Lake Ontario (Gal et al. 2004, Boscarino et al. 2010) and elsewhere (Rudstam et al. 1989, Levy 1991, Axenrot et al. 2009). The size distribution of mysids will be used to calculate average acoustic backscattering (target strength) from mysids using available scattering models based on fluid-filled bent cylinders (Stanton and Chu 2000) as applied to freshwater mysids by Rudstam et al. (2008a). Methods for whole lake estimates of mysid abundance using 120 kHz were developed by Rudstam et al. (2008b) and density estimates compared well with net data in 2005 to 2009 (Schaner et al. manuscript in prep). Although useful information can be obtained with one frequency, the use of two frequencies greatly enhances our ability to discern mysids from zooplankton. Acoustics backscattering is highly non-linear with animal size (Simmonds and MacLennan 2005, Rudstam et al. 2008a). We used 120 and 430 kHz units in Lake Ontario in 2008 (Fig 1). Both mysids and zooplankton are present in the 430 kHz data (see also Holbrook et al. 2006), but mysids are the main component of the scattering at 120 kHz. The difference between the two frequencies is therefore a good indicator of the identity of the animals in the scattering layer (Foote and Stanton 2000). We have completed preliminary analysis of acoustic data from others large lakes (Michigan, Huron, Superior, Champlain and so far the methods developed in Rudstam et al. (2008b) appear appropriate also in these lakes. [redacted] at USGS is also getting good results from using 38kHz to remove fish data from 120 kHz data in Michigan and Huron using the methods described in Rudstam et al. (2008a, b). Thus we are gaining confidences that hydroacoustics will work well for estimating mysid abundance across the Great Lakes. A major advantage is that hydroacoustics surveys are completed on each of the Great Lakes each year by USGS, OMNR, and state agencies, and these data can be analyzed for mysid abundance.

Abundance measures are not useful without including a measure of the uncertainty associated with the estimate. We are working on developing the methods for estimating the combined uncertainty in mysid abundance obtained with hydroacoustics (Sullivan and Rudstam 2011). In addition to traditional consideration of spatial variance, acoustic surveys include uncertainty about the target strength of the individual animals, the effectiveness of the mask for removing fish targets, calibration, and acoustic noise. These components of uncertainty all need to be accounted for when estimating mysid abundance. We are approaching this with a Bayesian framework and a Monte Carlo Markov Chain (MCMC) derived estimator of the combined uncertainty. This work for Lake Ontario is part of current GLRI funding to [redacted] and [redacted] To date, this analysis underlines the need to better define mysid target strength. This requires comparisons of net samples and acoustics, and we would like to obtain such samples across the Great Lakes to improve on the relationships in Rudstam et al. (2008a). We are collaborating with

USGS to obtain additional such data from Michigan, Huron and Superior. We envision also including such sampling for each of the Great Lakes during the associated CSMI year.

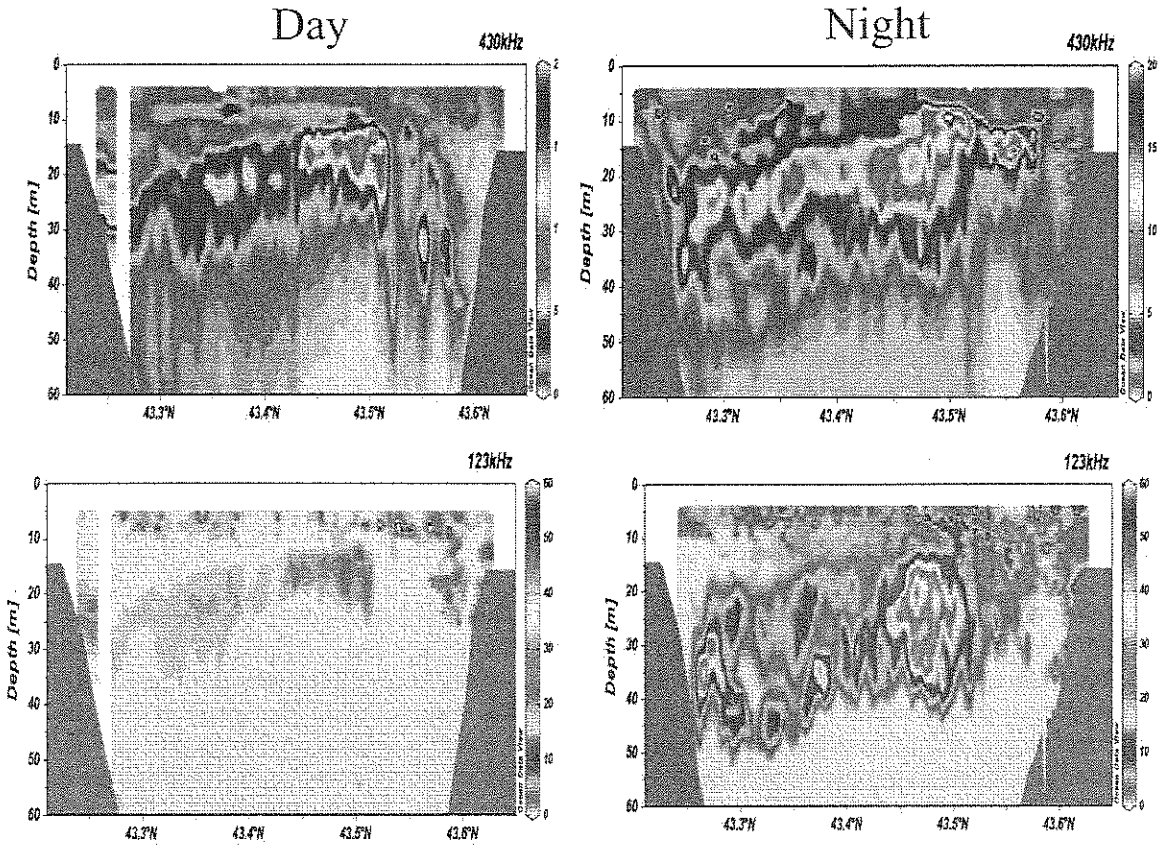

Figure 1. Acoustic backscattering at 430 kHz (top panels) and 123 kHz (bottom panels) during the night on July 22, 2008 along a N-S transect across western Lake Ontario. Much of the acoustic backscattering at night is from mysids as evidenced by the higher return in 123 kHz during the night. Warmer colors indicate higher acoustics biomass. Visualization of acoustic data using the Ocean Data View program.

2) Compare mysid abundance, growth and condition across the four deep Great Lakes. Acoustic surveys of all of the four deep Great Lakes will be used for mysid abundance estimates. Mysid net tows taken at night in association with these surveys and/or by the Lake Guardian will provide animals for measuring size structure and growth rates. Mysids have 18 month to 2 year life cycles in these lakes (Johannsson et al. 1994), and it is often possible to separate the two cohorts in size distributions and estimate growth rates, especially if samples can be collected in both April and August. We will also estimate lipid content of animals as an index of condition using standard methods (see Watkins et al. 2012). Abundance, growth and condition will be compared across and within lakes. Mysid distribution is patchy and increases with bottom depth in at least Lake Ontario, Superior, and Michigan (Johannsson et al. `1994, Rudstam pers. obs), so this comparison will require bottom depth as a covariate.

3) Evaluate mysid diets through stomach analyses, stable isotopes, and genetic markers. Mysid diets can be studied through stomach analyses where diagnostic parts of zooplankton and diatom prey are

enumerated (see e.g. Rudstam et al. 1989, Johannsson et al. 2003). We will analyze stomach content for 10 animals in each cohort per sample in up to 10 samples per lake. We expect that there is a gradient in the amount of predation versus herbivory in mysids associated with the relative importance of the DCL in the different lakes. Stable isotopes are additional indicators of prey selection. We have worked with stable isotopes in the past (Johannsson et al. 2001) and recent work by Sierzen et al. (2012) used stable isotopes to estimate the degree of benthivory in mysids across a depth gradient in Lake Superior. We will freeze animals collected during the CSMI years for stable isotope analysis, including samples of algae, detritus, *Diporeia* where available, and zooplankton. We reserve $2000 per year for stable isotope analyses at the Cornell stable isotope laboratory ($10 per sample, 200 samples per year)

We also plan on using quantitative PCR to estimate the amount of specific diet items consumed by mysids. This method has been used successfully to determine presence of the harmful algae *Nodularia* in mysids and copepods and the presence of *Cercopagis* in mysids in the Baltic Sea (Gorokhova and Lehtiniemi 2007, Gorokhova and Engström-Öst 2009). We will work with [redacted] at Stockholm University to find appropriate primers for DCL algae and amphipods, two prey groups that may be important component of mysid diets but are not well quantified in visual inspections of gut content. Laboratories with capability of qPCR analyses are available at Cornell University with potential collaborators [redacted] in the Department of Natural Resources and [redacted] College of Veterinary Science). We have discussed this possibility with both [redacted] and [redacted] and intend to pursue this further during fall 2012. Sample processing cost per diet item is approximately $10. We reserve $2000 per year for qPCR analyses.

4) Compare vertical distribution of mysids in the different lakes with predictions from a model relating distribution to light and temperature gradients. Mysid distribution is often restricted to a narrow depth layer during the night. [redacted] and students developed a model of mysid preferences to light and temperature based on laboratory experiments that predicted the distribution in the Lake Ontario across seasons and at new and full moon (Boscarino et al. 2009). We will use this model to predict the vertical distribution of mysids across the Great Lakes. Success would indicate that mysid distributions are highly predictable across systems and can be used to drive predictions of the spatial component of mysid food web effects. If less successful, we will explore the conditions that result in deviations from the predicted distribution. For example, it is reasonable to assume that mysids will move up to the DCL and not further even if the DCL is not located at the predicted depth based on laboratory preference experiments.

Model predictions require accurate temperature and light measurements. Temperature profiles will therefore be obtained at the sampling sites, which is standard practice. Light is more problematic as this is difficult to measure during the night and in addition should be measured in units appropriate to mysid vision. We use the unit mylux, which is derived similarly to lux as related to human vision. This can be measured with a light meter equipped with appropriate filters (Boscarino et al. 2009). We have two such meters and propose to affix one of them to the Sea Bird temperature profiler and one of them located on the ship to measure night-time light levels. Here we propose to purchase two additional light meters (Wildlife Computers MK-9) both as a backup for existing units and for lending to our collaborators (cost $1500 per unit).

5) Evaluate the importance of mysids in the food web of each of the four deep Great Lakes and compare this with fish zooplanktivory. With the information on mysid abundance, diet and growth rates, we can calculate mysid consumption of different diet items using a bioenergetics model. We will use the model by Rudstam (1989) that has been shown to predict growth and consumption in mysids in both North American lakes (Chipps 1998) and the Baltic Sea (Gorokhova 1998) – see also Bunnell et al. (2011). This analysis will provide the input needed for food web models that are currently being developed in all the Great Lakes using Ecopath with Ecosim (Bunnell, USGS pers. comm.). Ecopath with Ecosim requires input of abundance, production/biomass, diet, and consumption/biomass ratios; information that

is obtained through these analyses. In addition, we will compare the results with estimates of planktivory of the fish populations in the different Great Lakes (smelt, alewife, and coregonids). We hypothesize that mysid zooplanktivory is as high or higher than that of fish in all the Great Lakes, not only in Lake Ontario (Gal et al. 2006) and Lake Huron (Bunnell et al. 2011). Understanding of the Great Lakes food web dynamics and the associated predictions for fisheries management and stocking rates therefore need to include mysids.

Project 3. Invasive species detection [redacted].

Detecting new species is often difficult in biological monitoring program because they are rare and may be similar in appearance to existing species. There is no easy solution to this problem. Genetic techniques are gaining in popularity (Jerde et al. 2011) but will not work unless there is a known primer for a species specific section of DNA. Thus, the new species have to be identified first before genetic methods can be developed. Environmental DNA as a detection tool has promise for invasive species detection, but there are still questions about detectability (see discussion between Casey et al. 2012 and Jerde et al. 2012). We are collaborating with [redacted] at Cornell to test for the use of eDNA to detect invasive fish species (round goby) through other projects.

Therefore, it is our opinion that there is still no "short-cut: to careful observation and good taxonomical expertise. We have considerable experience with both zooplankton and benthos and the technicians that will be involved with zooplankton identification have between 4 and 6 years of experience with Great Lakes zooplankton [redacted] and [redacted]. However, keying out new species may be difficult due to poor representation in English language literature. Our group includes scientists with substantial experience in Europe and with the animals that are most likely to invade the Great Lakes in the future. [redacted] and [redacted] are leaders in the field of invasive species, in particular with benthic species. In addition, they are native Russian speakers, and have access to both the Russian literature and to colleagues in Russia with taxonomic expertise. [redacted] worked in Sweden with plankton in the Baltic Sea for his PhD and has also many colleagues around the Baltic Sea that can help with identification of new species for the Great Lakes. Although less literature is in his native language Swedish, he can also read literature in French and German. Together, these three scientists cover both the Ponto-Caspian region and the Baltic Sea, two of the major source areas for Great Lakes invasives (Ricciardi and MacIsaac 2000). Note that we have a long tradition with invasive species at the Cornell Biological Field Station (Mills et al. 1993, Holeck et al. 2004, 2007) and that we were among the first group to identify both *Cercopagis pengoi* (Makarewicz et al. 2001) and *Hemimysis anomala* (Walsh et al. 2010) in Lake Ontario.

The Ponto-Caspian region (consisting of the Black Sea, the Sea of Azov, and the Caspian Sea) has been a major source of Aquatic Invasive Species (AIS) to the Great Lakes: it was shown that approximately 70% of invading species discovered since 1985 are native to the region (Ricciardi and MacIsaac 2000), including species that have had strong impacts in the Great Lakes (e.g., dreissenid mussels, the round goby). The rich biota of the Ponto-Caspian region coupled with a high volume of commercial shipping traffic strongly suggests that this region will continue to be a major source of AIS to the Great Lakes (Holeck et al. 2004). In 2010 together with our colleagues [redacted] (Buffalo State College) and [redacted] (New York Sea Grant) we received an EPA GLRI award entitled *Evaluating Ponto-Caspian Fishes for Risk of Great Lakes Invasion*. Within this project we traveled to Russia to examine unpublished reports and/or untranslated publications, obtained detailed information on additional Ponto-Caspian fishes, and performed statistical analyses following Kolar and Lodge (2002) on an additional 43 Ponto-Caspian fishes for which data had previously been incomplete or unavailable. As a result of our analysis, we were able to identify an additional four species of Ponto-Caspian fishes that are at high risk of invading the Great Lakes. A subsequent proposal to assess geographic distributions and "propagule pressure" for these high-risk Ponto-Caspian fishes in key European shipping ports entitled "*Enhanced*

Early Detection of Invasive Ponto-Caspian Fishes in the Great Lakes" has just been selected as a finalist in the Great Lakes National Program Office's 2012 GLRI competition. Within this project we will identify high-risk locations and high-risk time periods in Great Lakes ports to focus surveillance and early detection efforts for invasive Ponto-Caspian fishes. We will use these same identified locations to monitor for potential invasive Ponto-Caspian invertebrates and integrate this activity within existing AIS outreach efforts (e.g. GLANSIS). Since surveillance and early-detection teams must make decisions about deploying scarce resources in a manner that maximizes the probabilities of detecting rare, newly-introduced species (Hoffman et al. 2011), being able to focus surveillance activities on specific locations in and around each of these high-risk ports would be a tremendous advantage for early detection and effective responses to an invasion.

As a part of the GLRI 2012 project, we will bring voucher specimens of high-risk Ponto-Caspian fishes from Russia for surveillance and early response teams to support rapid and accurate identification of potential new invasive fishes. Here we will expand on this activity by also bringing in specimens of predicted invertebrate invaders obtained during this trip and also using our net of collaborators in Europe and Asia and perform similar analyses on these invertebrates as for the fish taxa proposed in the hopefully supported GLRI 2012 proposal. We will review the potential genetic primers for these species using genomic databases. If none is available, we will seek funds to develop such primers which can be used as an early warning system for these species. Depending on who the eDNA method stands the test of time, we will initiate collaborations with [redacted] and [redacted] in the Cornell Veterinary School (that are working on problems with eDNA detections of invasive species of fish) to also include invertebrates.

Project 4. Compare existing and develop new benthic community biological indices for macroinvertebrate bioassessment (M.A. student, [redacted]

Traditional chemical water quality monitoring can be minimally informative for the overall stress of ecosystems. Meanwhile, biological communities often reflect the overall ecological integrity (i.e., chemical, physical, and biological) by assimilating stresses over time and thus providing an ecological measure of fluctuating environmental conditions (Barbour et al 1999). Biological monitoring using benthic macroinvertebrates is one of the most reliable and cost-effective approaches for assessing ecosystem health because benthic communities are very sensitive to environmental disturbances. Benthic macroinvertebrate assemblages are considered to be among the best for environmental monitoring because they include species constituting a broad range of trophic levels and pollution tolerances, thus providing strong information for interpreting cumulative effects of multiple stressors and understanding the source of pollution (Rosenberg and Resh, 1993; Resh and Jackson, 1993; Barbour et al., 1999; Purcell et al. 2009). They are good indicators of localized conditions and site-specific impacts and, importantly, they integrate the effects of short-term environmental variations, as the sensitive life stages respond quickly to stress, but the overall community responds more slowly.

Benthic indices provide assessment for stressors such as eutrophication, sediment deposition, pollution, and stormwater runoff point sources that often accompany chemical contamination of the water column in water bodies facing multiple anthropogenic impacts. Major categories of benthic metrics currently used in indices for bioassessment vary and have to be adjusted for geographical variation and particular anthropogenic impairment, but the most effective are the taxa richness, tolerance/ intolerance measures, and feeding measures categories (Resh and Jackson, 1993). EPA has adopted Milbrink's modifications of Howmiller and Scott's original index based on the association of oligochaetes with organic enrichment of water that combines abundance of certain oligochaete groups with their preference or tolerance for specific trophic condition. However, it seems that in certain cases the trophic status of a lake classified based on this oligochaete community index does not work well. For example, according to the SOLEC "State of the Great Lakes 2012" draft report on benthos diversity and abundance, "the most eutrophic conditions in Lake Erie were found in the eastern basin, which tended to increase up until about 2003 and

remain … through 2009". Based on our intensive sampling of Lake Erie in 2009 and 2011-2012 within the GLRI-funded projects NOLENS and LENONS, we found that the eastern basin of Lake Erie is the most oligotrophic of all other basins, where the density and abundance of plankton were substantially lower than in other basins. This may indicate that different metrics of benthic community are needed to classify the lake trophic status. Specifically we propose to apply and compare the existing indices, including the EPA-adopted index and other promising stressor-specific bioindicator systems designed in the USA and in Europe (Wiederholm 1980, Clarke and Warwick 2001, Uzarski et al. 2004, Borderelleet al 2005, Rossaro et al. 2006, Beketov and Liess 2008, Beketov et al. 2009, Gabriels et al. 2010) to the data collected during this project. We will perform field and laboratory experiments in order to understand the effect of dreissenids on nearshore *versus* offshore benthic communities. We will develop new multivariate benthic community biological indexes based on both density and biomass for various types of habitats in the Great Lakes, and compare collected data with previous and historical data. The results of the study will enable to compare the current status of benthic community of each of the Great Lakes and selected indicator benthic groups with previous and historical data to determine existing trends.

ii. Results- Outputs and Outcomes:

Our proposed project fits within Focus Area 5 of the Great Lakes Restoration Initiative Action Plan: Accountability, Education, Monitoring, Evaluation, Communication and Partnerships. The first stated long-term goal of this area is a cooperative monitoring and observing system that provides a comprehensive assessment of the Great Lakes ecosystem. Towards promoting this goal we will continue the long legacy of environmental monitoring by EPA's Great Lakes National Program Office using the R/V Lake Guardian.

Specific Project Outputs (see table below for timeline)

- Measurements of community composition and biomass for zooplankton and benthos in the five Great Lakes (420 zooplankton samples and 233 benthos samples per year for five years).
- Rapid reporting of invasive species detected in the zooplankton and benthos.
- Measurements of chlorophyll *a* across the five Great Lakes (1150 samples from the surface and specific depths for each year for five years).

These three outputs are direct products of our proposed project. Each April and August we will sample several long-term stations within all five Great Lakes. We will closely follow EPA's SOPs for sample collection, processing, and data management including specified QA/QC protocols. This diligence will ensure continuity within the long-term data set.

- Extended time series for lower food web indices (nutrients, plankton and benthos) for each Great Lake
- Document changes in biological community structure and biomass.

The data that we generate will extend the long-term time-series that is essential for evaluating the progress toward restoration of the Great Lakes ecosystem. We will take the aforementioned survey data and place it in the context of long-term sampling by GLNPO and other sampling programs and the scientific literature. Our group has experience assembling concurrent time series through our work on Lake Ontario that includes several statistical tools including change point analysis and ordination.

- Annual reports within 12 months of the completion of each survey as well as a final report including verified electronic databases compatible with GLENDA.
- Several peer-reviewed journal articles describing changes detected in Great Lakes through our sampling.

- Two workshops promoting consistency in taxonomic identification for Great Lakes zooplankton and benthos.
- Water column profile data package for visualization within software Ocean Data View.
- Color sections with contours for several water column profiles for the five Great Lakes constructed using Ocean Data View.

A primary goal of the GLRI is to rapidly distribute project deliverables that are public friendly, timely and available on the Internet. We will provide GLNPO with timely reports so that they can convey this updated information regarding the state of the Great Lakes. We also intend to publish our interpretations of these results within peer-reviewed journal articles as we have in our long-term research of Lake Ontario. We will organize and host two workshops for Great Lakes scientists to promote consistency in taxonomic identification for plankton and benthos. Another step toward improving the communication of GLNPO survey data would be to compile Seabird water column profile data from all available years into a single data file that can be visualized using the software Ocean Data View. This program is an important educational and research tool for visualization of marine data and could be similarly used to view data from the Great Lakes. Users can quickly generate color sections and maps of selected parameters to track physical and biological gradients across lake systems.

- Two Ph.D. recipients from Cornell University and one M.A. recipient from Buffalo State College in the Great Lakes Ecosystem Science Program.
- Ten undergraduates from Cornell University and 5 undergraduates from Buffalo State College receiving research experience in Great Lakes science.
- Ten or more peer-reviewed journal articles on topics including the increasing importance of the deep chlorophyll maximum, life history of *Mysis*, invasive species, benthos, benthic biotic indices,and modeling fish distribution.
- Acoustic-based monitoring plan for *Mysis* in the Great Lakes that combine USGS and EPA efforts.
- Written standard operating procedure for acoustic monitoring of *Mysis* and zooplankton.

These outputs will be direct benefits from our involvement of graduate and undergraduate students from Cornell University and Buffalo State College in this project. These students will assist in sampling and analysis and pursue several independent projects that will progress our understanding of key ecosystem components. These activities will broaden the application of EPA monitoring as well as fill current sampling gaps. Our goals include designing an acoustic-based monitoring plan complete with SOPs for *Mysis* in the Great Lakes together with USGS-GLSC. We collaborated on developing the SOP for fish acoustics in the past. Graduate students are an integral part of our existing program and will benefit from these additional resources and access to platforms.

Specific Project Outcomes

While maintaining continuity with previous sampling, we also intend to fill sampling gaps and foster coordination with outside sampling programs. This approach fits well with the following specific GLRI goal within the timeline of our project-

By 2014, a statistically valid and comprehensive assessment, using a probability-based design, of Great Lakes water resources, will be established. The system will integrate shipboard monitoring, remote sensing, automated sampling, and other monitoring or observing efforts. By 2016, the system will be in place for all of the Great Lakes and capable of providing a scientifically justifiable assessment of Great Lakes water resources.

Specific outcomes toward this goal include

- Improved coordination of GLNPO's surveys with other US and Canadian shipboard sampling programs.
- Integration of buoy and remote sensing platforms into annual GLNPO sampling.
- Development of a new coordinated monitoring plan for the Great Lakes.
- Incorporation of sampling tools to fill gaps in GLNPO sampling (e.g. acoustic-based sampling system for *Mysis* and zooplankton).

These four outcomes will fill recognized spatial and temporal gaps in the existing monitoring design. Improved coordination of the several different agencies that currently monitor the Great Lakes will reduce overlap and broaden their collective significance. Our strong existing relationships with several federal, state, and provincial agencies will aid in this goal. Our expertise in sampling design and the use of new sampling tools and remote sensing make us important contributors to the planning of a comprehensive monitoring system by 2016.

Other project outcomes will improve responses to invasive species in the Great Lakes basin-

- Improved invasive species detection system.
- Improved effectiveness in controlling introductions of invasive species to the Great Lakes.
- Improved ability to determine effects on the lower food web and fisheries in impacted lakes.

Our benthos group is particularly well suited to promote these outcomes because of their familiarity of the Russian scientific literature. They have been involved in projects that predict potential new invaders based on environmental tolerances and vectors. The benthos and zooplankton groups are both skilled at identifying current invasive species and reporting to invasive species lists that describe expanding ranges. Both groups have a long history of evaluating impacts of invasive species in the Great Lakes and smaller lakes.

-Improved linkage of GLNPO's lower food web data to fishery managers in the Great Lakes.

Our group's expertise in fish ecology and bioenergetics and our close relationships with fishery managers will help extend GLNPO survey data to predicting potential changes to fish populations that can guide management decisions. This topic is particularly relevant in the present day as fishery managers in Lake Michigan and Huron quickly reassess existing stocking programs due to the transition of these lakes toward lower productivity and hence lower carrying capacity for fish. Alewife stocks collapsed in Lake Huron in 2003-dramatically impacting an economically important salmon fishery. Similar impacts are now seen in Lake Michigan and anticipated by some in Lake Ontario. Our group's lower food web work currently is used as one source of background information for stocking decisions for the economically important Chinook salmon fishery for Lake Ontario as well as for restoration efforts for native coregonids.

Project Timeline, Oct 2012-Sept 2017

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
2012-2013												
Taxonomic Workshops	x	x										
Sample Analysis and Data Management, 2012 Survey	x	x	x	x	x	x						
Report on 2012 Survey Data						x						
Preparation and Field Surveys						x	x			x	x	
Lake Ontario CSMI Support	x	x	x	x	x	x	x	x	x	x	x	x
Lake Committee and IAGLR Meeting						x		x				
Sample Analysis, 2013 Survey								x	x	x	x	x
Research Projects	x	x	x	x	x	x	x	x	x	x	x	x
2013-2014												
Sample Analysis and Data Management, 2013 Survey	x	x	x	x	x	x						
Report on 2013 Survey Data						x						
Preparation and Field Surveys						x	x			x	x	
Lake Erie CSMI Support	x	x	x	x	x	x	x	x	x	x	x	x
Lake Committee and IAGLR Meeting						x		x				
Sample Analysis, 2014 Survey								x	x	x	x	x
Research Projects	x	x	x	x	x	x	x	x	x	x	x	x
Peer-Reviewed Paper Prep	x	x	x	x	x	x	x	x	x	x	x	x
Mysis Sampling SOP												x
Ocean Data View Package												x
2014-2015												
Sample Analysis and Data Management, 2014 Survey	x	x	x	x	x	x						
Report on 2014 Survey Data						x						
Preparation and Field Surveys						x	x			x	x	
LakeMichigan CSMI Support	x	x	x	x	x	x	x	x	x	x	x	x
Lake Committee and IAGLR Meeting						x		x				
Sample Analysis, 2015 Survey								x	x	x	x	x
Research Projects	x	x	x	x	x	x	x	x	x	x	x	x
Peer-Reviewed Paper Prep	x	x	x	x	x	x	x	x	x	x	x	x

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
2015-2016												
Sample Analysis and Data Management, 2015 Survey	X	X	X	X	X	X						
Report on 2015 Survey Data						X						
Preparation and Field Surveys						X	X			X	X	
Lake Superior CSMI Support	X	X	X	X	X	X	X	X	X	X	X	X
Lake Committee and IAGLR Meeting						X		X				
Sample Analysis, 2016 Survey								X	X	X	X	X
Research Projects	X	X	X	X	X	X	X	X	X	X	X	X
Peer-Reviewed Paper Prep	X	X	X	X	X	X	X	X	X	X	X	X
2016-2017												
Sample Analysis and Data Management, 2016 Survey	X	X	X	X	X	X						
Report on 2016 Survey Data						X						
Preparation and Field Surveys						X	X			X	X	
Lake Huron CSMI Support	X	X	X	X	X	X	X	X	X	X	X	X
Lake Committee and IAGLR Meeting						X		X				
Research Projects	X	X	X	X	X	X	X	X	X	X	X	X
Peer-Reviewed Paper Prep	X	X	X	X	X	X	X	X	X	X	X	X
Final Project Report												X

iii. Collaborations, Partnerships, and Overarching Plans

[redacted] and [redacted] have collaborated on projects associated with benthic mussels and other mollusks for several years. The collaboration proposed here between Cornell University and Buffalo State College will continue and expand this collaboration while using the strengths of both research groups (zooplankton and mysids at CBFS and benthic invertebrates at Buffalo State). Both the Cornell Biological Field Station and the Great Lakes Center at Buffalo State College have a long tradition of working collaboratively with managers and agency scientists in both the US and Canada.

[redacted] is part of the NYSDEC Lake Ontario Technical Committee and has served on the Lake Erie forage fish task group. [redacted] is also an active participant in the Lake Committee meetings of the Great Lakes Fisheries Commission and often presents and interprets lower trophic level data for fisheries managers (see also outreach section) and he serves as Cornell University's representative in the Great Lakes Research Consortium. The interest in lower trophic levels among fisheries managers in New York and Ontario is encouraging and led to the collaborative NYSDEC/USGS/USFWS/Cornell Biomonitoring program. This will continue and is another avenue for connections between fisheries and the rest of the ecosystem. As part of current GLRI grants as well as work with the Great Lakes Acoustic Working Group and additional connections, [redacted] has active collaborations with researchers in federal, provincial and state agency across the Great Lakes Basin. Active project co-PIs and co-authors on submitted and recently published report and papers (since 2010) include scientists at USGS-Oswego,

USGS-Sandusky, USGS-Ashland, USGS-GLSC, OMNR-Glenora, OMNR-Erie Station, DFO-Canada, Environment Canada, EPA, NYSDEC, NOAA-GLERL, Michigan DNR, USFWS-Buffalo, USGS-Coop Units in three states. In academia, a similar list of Great Lakes associated projects include scientists from SUNY-Buffalo, Michigan Tech, University of Minnesota-Duluth, SUNY-ESF in Syracuse, University of Vermont and University of Wisconsin-Milwaukee. These connections will continue and likely increase if we are awarded this project.

[redacted] is part of the Lake Erie Millennium Network and has active collaborations with NYSDEC, USGS, and USFWS. He also serves as Buffalo State College representative in the Great Lakes Research Consortium. As a part of current GLRI grants and grants funded by USFWS, [redacted] and [redacted] have active collaborations with researchers in federal, provincial and state agency and academic institutions across the Great Lakes Basin. Active project co-PIs and co-authors on submitted and recently published report and papers (since 2007) include scientists at USGS Great Lakes Science Center, Central Michigan University, Cornell University, Cleveland State University, Heidelberg University, University of Toledo, Kent State University, NY DEC, USFWS-Buffalo, Western Pennsylvania Conservancy, Pennsylvania Natural Heritage Program, Case Western Reserve University, Miami University, New York State Museum, University of Wisconsin – Madison, Stony Brook University, SUNY-Buffalo, SUNY-ESF in Syracuse. This active collaboration and connections will likely increase if this project will be awarded.

The proposed project will complement other existing surveys of zooplankton and benthos in the Great Lakes. We are already heavily involved in such programs in Lakes Ontario and Erie and are looking forward to form similar collaborations across the basin. Of great importance for the use of the data collected by EPA is the timely dissemination and easy availability of the data (see Holeck et al. 2012 and Rudstam et al. 2012 for current approaches by CBFS). When data are available, the information will get used (as already shown for the GLENDA database). We are strong proponents of an ecosystem-based approach to fisheries management in the Great Lakes and work actively with merging ecosystem and fisheries data for a more comprehensive understanding of these important resources. If anything can be considered an overarching plan, it would be to contribute to a comprehensive and available monitoring program in the Great Lakes that is useful and available to increase our understanding of these important ecosystems and guide management.

Other stakeholder engagement is described under education/outreach.

iv. Programmatic Capability and Past Performance

The PI and co-PIs are established scientists in the Great Lakes region working with crustacean zooplankton, mysids and fish in the open water and with benthic invertebrates, especially *Diporeia* and mussels. [redacted] is the director of the Cornell Biological Field Station and a professor in the fisheries and aquatic sciences at Cornell University. He has graduated eight Masters and Ph.D. students working on the Great Lakes, several of whom are active in Great Lakes research. He is an internationally recognized authority on mysid ecology (author of the mysid chapter in the encyclopedia of inland waters in 2009), but has also published several papers on zooplankton based on his own identifications (including work with mysid diets and identifications using zooplankton parts). He has worked with predatory zooplankton such as *Cercopagis* and grazers such as *Daphnia*. Currently he leads the Cornell program on lower trophic levels in Lake Ontario (see below). He is well connected with the fisheries management agencies in New York State and elsewhere and advice on fisheries issues through the Lake Ontario Technical Committee. In the past, he worked with fisheries issues in Lake Michigan and mussel effects and smelt-*Bythotrephes* dynamics in Lake Erie. He served 6 years as a core member of the GLFC Board of Technical Experts (BOTE), is an Associate Editor of the Journal of Great Lakes Research and Aquatic Ecosystem Health and Management, and a special issues editor for mysid biology in Aquatic Biology (2008-2009) and for fish sampling with active gear in Fisheries Research (2010-2012). He wrote

the chapter of fisheries acoustics in the American Fisheries Society's Fisheries Technique text (Rudstam et al. 2012) and led the Great Lakes Acoustic Working Group for 10 years. Professor [redacted] is the lead PI on this project and in addition to overall oversight of the project will advise the graduate students and work with developing new sampling techniques for integrating acoustics, buoys, satellites and models into the EPA-BMP. He requests one month of summer support.

Dr. [redacted] is an internationally recognized expert in invasive biology and benthic ecology, including the ecology, biology, and spread of aquatic invasive species and their role in aquatic ecosystems, as well as the taxonomy, biology, ecology and long-term dynamics of benthic communities, particularly their use as indicators of changes in aquatic ecosystems. Over the last 35 years of active research he has published 120 papers on various aspects of benthic ecology and AIS both in Europe and North America. He has worked with invasive bivalves such as *Dreissena polymorpha*, *D. rostriformis bugensis*, *Corbicula fluminea*, and *Limnoperna fortunei*, and made a strong contribution toward understanding their role as ecosystem engineers, capable of altering the invaded ecosystem. He was also involved in the long-term monitoring of the benthic community of Lake Mendota, Wisconsin. Currently he is the director of the Great Lakes Center at Buffalo State College that maintains a strong research program in the lower Great Lakes, including several EPA funded projects. The Center is also involved in the monitoring of the lower food webs in the Lake Erie in collaboration with USFWS. [redacted] is well connected with the AIS and fisheries management in state and federal agencies. Professor [redacted] is a Co-PI on this project and will be involved in all aspects of benthic and AIS study, including sampling, samples identification, data analysis, and report writing. He will be also involved in the development of new indices and graduate student advising.

Dr. [redacted] is a Research Scientist and Principal Investigator with over 20 years of research experience in aquatic ecosystems. Her research interests include ecology and diversity of benthic communities, and aquatic invasive species (i.e., *Dreissena polymorpha, Dreissena r. bugensis, Corbicula fluminea, Pomacea insularum, Limnoperna fortunei*). Dr. [redacted] research in ecology, biology, parasitology, and patterns of spread of aquatic invasive molluscs and their role in benthic communities and freshwater ecosystems received international recognition. She has an extensive experience in data processing and statistical data analysis, in the design and execution of lake-wide benthic and *Dreissena* surveys, and she is well connected around the Great Lakes region. [redacted] has several years of experience in collecting and analyzing data on the benthic community and AIS of Lake Erie, performed a lake-wide survey of freshwater mussels Unionidae in Lake Ontario refuges in 2012, and has spent time in 2009 on the Lake Guardian associated with her work on NOLENS project and her research on *Dreissena*. She has published 59 peer-reviewed scientific articles, and made over 60 invited talks and presentations at scientific meetings. Her research has been funded by federal and state agencies including U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, U.S. Department of Agriculture, Texas Parks and Wildlife Department, Texas Water Development Board, Wisconsin Department of Natural Resources, and Texas Army National Guard. She is a soft-money scientist and an Adjunct Associate Professor at Buffalo State College and at the University of Buffalo. [redacted] is a Co-PI on this project and will be involved in all aspects of benthic and AIS study, including sampling, taxonomic identification, data analysis, graduate student supervision, and report and manuscript writing. She will be responsible for grant management for the Buffalo State College component. We request 7 months of support for Dr. [redacted]

Dr. [redacted] will be the Research Associate in charge of day-to-day activities associated with primarily the standard sampling and processing. He will also be involved with the research projects including the DCL analyses and comparative ecology of mysids. [redacted] has several years of experience on all the Great Lakes and has spent considerable time on the Lake Guardian associated with his work on *Diporeia* and is well connected around the Great Lakes region. Prior to his PhD studies at Cornell University (degree in 2011), he received a M.Sc. for work in oceanography and spent time as an instructor

with the Sea Semester program that takes undergraduate students across the Pacific or Caribbean on a sailing ship while teaching them about oceanography and marine biology. This background is useful for bringing a marine perspective to the study of Great Lakes and for the outreach component of this study. We request 12 months of support for Dr. [redacted]

[redacted] is a Research Support Specialist and the lab manager at CBFS. She will coordinate the connection between the Biomonitoring program of New York DEC and this project. She has 10+ years of experience working with zooplankton and lower trophic levels in Lake Ontario and elsewhere and has published several papers on biological invasions (Holeck 2004, 2007) and on zooplankton dynamics (Holeck et al. 2008). She will work with [redacted] and [redacted] on reports and database issues and will help with zooplankton identification as needed. We request 2 months of support for Ms. [redacted] during the initial two years and the final year of the project when she will participate in setting up the study and laboratory and with writing the final report, and 1 month of support for the other two years.

In recent years, the PI and co-PIs have held several federally funded projects. Here we comment on the deliverables and the timely completion of three projects for PI Rudstam and three projects for co-PI [redacted] and [redacted]

Developing the next generation of Great Lakes lower foodweb assessment tools – Status of the Lake Ontario Food web in a changing ecosystem (PI- [redacted] *Co-PI* [redacted] *EPA, $100,000, 2005-06.*
For this project, we analyzed the status of the lower trophic levels of Lake Ontario and contributed to the planning for the 2003 intensive sampling year of Lake Ontario. All quarterly and annual reports were completed on time, databases delivered to EPA, two workshops held (one at the Cornell Biological Field Station and one in Kingston, Canada) and several papers published in the peer-reviewed literature that includes the PI, the proposed Research Associate ([redacted] and the Research Support Specialist ([redacted]). This work has resulted in 5 peer-reviewed publications in Aquatic Ecosystem Health and Management and the Journal of Great Lakes Research (Holeck et al. 2008, Rudstam et al. 2008b, Watkins 2009, 2010, Watkins et al. 2007). Students and technicians from CBFS were also involved in field sampling.

Forecasting ecosystem effects of a new invader, Hemimysis anomala, in Lake Ontario (PI- [redacted] *Co-PI* [redacted] *New York Sea Grant $120,000, 2009-2011.*
This project was completed in the June of 2011 after a 4 month no-cost extension. Annual progress reports and the final report were delivered on time. The project involved collaborations with USGS-Great Lakes Science Center scientists on Lake Ontario. Experiments were completed on bioenergetics of *Hemimysis*, prey selection and habitat choice, and several are now published with at least three additional manuscripts close to submission. The results were also part of a special volume on *Hemimysis* and *Mysis* biology in the Journal of Great Lakes Research (Brooking et al. 2010, Walsh et al. 2010, Boscarino et al. 2012, Taraborelli et al. 2012, Lantry et al. 2012, Walsh et al. 2012).

Status of Lake Ontario in 2008 – Great Lakes Restoration Initiative (PI- [redacted] *Co-PI* [redacted] *Environmental Protection Agency $330,000, 2010-2012.*
This GLRI funded project is intended to analyze the lower trophic level assessment of Lake Ontario in 2008 and provide databases of the data to EPA and also made available on the web. Workshops were held at the Cornell Biological Field Station and Department of Fisheries and Oceans, Burlington Canada. The final workshop for stakeholders is planned for September 26, 2012 at Cornell. The project is an excellent example of our ability to collaborate with both US federal and state agencies and with our Canadian colleagues. The report on the status of Lake Ontario is being reviewed by the collaborating agencies and will be finalized by the middle of August, 2012. Databases are available on the Knowledge Network for Biocomplexity (http://knb.ecoinformatics.org/index.jsp). The strength of this analysis lies in

the combination of data on lower trophic levels from a variety of sources, including USGS, NYSDEC, OMNR, Environment Canada, and DFO Canada. A special session on Lake Ontario was held at the IAGLR meeting in spring of 2012 and a special volume on Lake Ontario edited by [redacted] and [redacted] is planned with manuscript deadline December 15. Presentations were given at the workshops and at IAGLR meetings in 2011 and 2012. [redacted] also presented data from this project at the State of Lake Vanern conference in Sweden in June 2012 and we contributed to the SOLEC indicators on invasive species ([redacted]. Cornell students and faculty also participated in the field sampling. Funds allocated to this project have been used primarily for salaries and student/postdoctoral support. The quarterly rate of expenditure follow planned activities, QAPP accepted within a reasonable time and all quarterly reports up to date. Proportion of funds spend at different quarters were Q1 0%, Q2: 11.9%, Q3: 3.6%, Q4: 28.1%, Q5: 21.1%, Q6: 17.1%, Q7: 7.3%, and Q8: 10.6%. 99.7% of the funds have been spent to date and most of the remaining activities are associated with writing manuscripts based on these analyses.

Great Lakes Restoration Initiative – US EPA: "Evaluating Ponto-Caspian Fishes for Risk of Great Lakes Invasion – GL00E00498" (PI- [redacted] *Co-PI's:* [redacted] *$111,264, 2010-2012.* A major objective of this project is to supplement current lists of high-risk fish invaders from the Ponto-Caspian region by identifying new high-risk species via a review of the extensive Russian literature on these species. This objective has been completed, and the results (4 new high-risk species identified) were recently presented at the 2012 IAGLR conference in Cornwall, Ontario. The analysis of ballast water survival of the high-risk species is ongoing, and production of fact sheets and informational PowerPoint presentations is in progress; both components will be completed by the completion date of the project (8/31/12). All 6 required GLAS reports and all 3 required semi-annual progress reports were filed by the deadlines. All project deliverables will be completed by the project end-date of 8/31/12.

Great Lakes Restoration Initiative – US EPA: "The Lake Erie Nearshore and Offshore Nutrient Study (LENONS)" (PI- [redacted] *multiple Co-PI's including* [redacted] *$615,813, 2011-2013.* This is a multi-investigator, multi-institution (5 universities) award to quantify all the major biotic and abiotic nutrient pools, flux rates, and trophic pathways in the nearshore and offshore regions of Lake Erie, and to assess whether the pools of nutrients in the nearshore and offshore regions follow the predicted patterns of lake mixing models and the nearshore shunt hypothesis. Each Co-PI has provided a semi-annual report to the PI for assessment of data completeness and data quality, based on evaluations at each Co-PI institution. Reporting is complete to date. Presentations were prepared for the Ohio Academy of Sciences annual meeting, as well as IAGLR in 2012. Several publications are also in preparation.

Great Lakes Fish and Wildlife Restoration Act – U.S. Fish & Wildlife Service: "Conservation of native freshwater mussel refuges in Great Lakes coastal zones" (PIs- [redacted] *and* [redacted] *and other Co-PIs) $366,412, 2010-2013.* This is a multi-institutional award involving 10 Co-PI's and 6 collaborators from 12 institutions, and [redacted] one of the main PIs responsible for study design, data analysis, and for the surveys of Lake Ontario. This project involves surveying of unionids in known and predicted refuges in the lower Great Lakes, sampling of key habitat attributes in these refuges, and examination of unionid genetic diversity/isolation to determine if there is gene flow between coastal refuges and nearby riverine habitats. Based on collected data, predictive models will be developed to determine the set of habitat parameters necessary to sustain unionid populations and to predict the locations of as-yet undiscovered refuges in the Great Lakes. This project will provide managers with information to locate and protect additional unionid refuges and also to manage sites to promote unionid colonization and survival and to develop conservation strategies to sustain existing populations in these refuges. Each co-PI has provided a semi-annual report to the PI and the reporting is complete to date. Multiple presentations were prepared for the IAGLR 2011 and 2012, and for the 2012 International meeting on Biology and Conservation of Freshwater Bivalves in Portugal. Several M.S. theses, a Ph.D. thesis (supervisor [redacted]) are in preparation. The results of the project will be published in a special volume on Unionidae in the Journal of Great Lakes Research in 2013-2014.

v. Education/Outreach

Both the Buffalo State and the Cornell groups are collaborating with New York Sea Grant Extension and have projects involving Sea Grant extension specialists [redacted]. These collaborations work well in New York where results from the intensive surveys of Lakes Ontario and Erie are reported to stakeholders and managers at workshops. Project 3 on invasive species also includes an extension component through New York Sea Grant. Rather than duplicating this extension effort ourselves, we plan on providing updated state of the lakes data to Sea Grant offices around the Great Lakes each year, as well as to the extension effort of EPA. This will include visualization of the lakes that can be used in presentations and posters. Previous projects have included stakeholder meetings with interested public in both the US and Canada (project through Cornell University 2006-2009 with [redacted] as PI and [redacted] as co-PIs). Current GLRI funding includes a scenarios workshop that will be held at CBFS on September 26, 2012 with participants from the region working with tourism, charter, federal, state and tribe managers (from both the US and Canada).

Education and outreach are important elements of early detection of AIS. We will develop recommendations and materials including fact sheets, PowerPoint presentations, and web-accessible information for target audiences for the most effective education and outreach programs. With the help of NY Sea Grant and state and federal agencies, we will target as wide an audience of stakeholders as possible, including boaters, anglers, hunters, birdwatchers, fish and wildlife resource managers and field biologists, state and federal fish and wildlife pathologists, county health departments, researchers, veterinarians, and human health practitioners, and environmental interest groups, to increase awareness of the problem and actively involve them in the prevention of the spread of AIS. This will be implemented through public media, dissemination of flyers, posters, and presentations at public and scientific meetings. We will also create a web-page with the results of the project to provide a decision support tool for early detection and prevention of the spread of AIS. The Great Lakes Center developed and launched in 2012 a new website that features a modern design, updated content, and new photo galleries and videos. We will use this website to keep various regional stakeholders aware of the ongoing monitoring, AIS detection efforts, and project progress.

Buffalo State College is the largest of the State University of New York Colleges of Arts and Sciences, with more than more than 11,000 undergraduate and master's students, 130 undergraduate and 44 MA academic programs. The college's tradition of student involvement in undergraduate research was established with creation of the Office of Undergraduate Research (OUR) in 2003 (Singer and Weiler 2009). To present and disseminate the results of undergraduate research, BSC initiated a campus-wide annual event, Student Research and Creativity Celebration, where hundreds of students participate in the oral and poster sessions, and gallery exhibits. The Biology Department hosts the largest and most research-oriented program, the Aquatic Biology concentration, both in the number of faculty served, courses offered, and graduate and undergraduate students enrolled. This program benefits greatly from the Great Lakes Center, a multidisciplinary research, education, and service institute, the only SUNY field station located on the Great Lakes. GLC facilities include state-of-the-art laboratories at the Field Station and on the campus, a fleet of research vessels, a demonstration watershed for research and teaching, and a variety of sampling and analytical equipment. Our project will benefit students who will receive advanced training in aquatic ecology from faculty that are active in research, and from facilities available in the GLC. In return, the Department will benefit from our project through increased student involvement, scholarly activities, and student's academic achievements.

Cornell University is one of the top 15 research Universities in the USA with a large graduate program, but also a dedication to undergraduate education. The Department of Natural Resources is within the College of Agriculture Sciences. The Cornell Biological Field Station is staffed through this department.

CBFS has an established undergraduate intern program with students spending 11 weeks at the field station in the summer working with a research project in association with a graduate student or faculty mentor. The students also participate in other activities at the station and a summer seminar series. In the fall, these students' sign up for independent research credits and work with their advisors to analyze and write up data in a format of a scientific paper. They present their results at an undergraduate research symposium in the fall. About half of these papers are later incorporated in scientific publications. We also have a proven track record in educating K-12 teachers and their students about Oneida Lake in the local school system near Syracuse, New York through the Oneida Lake Education Initiative (http://www.seagrant.sunysb.edu/oli/olei-home.ht) in cooperation with New York Sea Grant. This includes lesson plans on food webs, invasive species control and basic limnology and fish ecology. We could easily expand this mission to Great Lakes issues in our region. Lesson plans that are developed can be transferred to other school systems within the Great Lakes basin. We are developing several short informative videos that can be easily posted on the web.

Much of the research CBFS and Buffalo State Great Lakes Center is communicated to the local press; for CBFS to the Syracuse Post-Standard and its website Syracuse.com via close ties with the Outdoors editor Dave Figura. Recent articles include our studies on the common tern, lake sturgeon, bass, and invading dreissenid mussels. These articles include photography and detailed information that informs our local community of our research.

Our stakeholder outreach program associated with this proposal is intended to bring the long-term data collection and analysis to both environment and fisheries managers and to the general public. We plan on participating (either directly or by providing data and interpretations) in a series of well-attended annual meetings that the New York Department of Environmental Conservation (NY DEC) organizes each winter to discuss the state of the Lake Ontario ecosystem and fishery with the public. Materials from our studies have been an important component of such meetings in the recent years (talks given by our collaborator [redacted]. Meeting sites cover the entire southern shoreline of Lake Ontario and are an important avenue for public outreach and similar meetings are held on the Canadian side. We will develop a contact network to provide updates to the various state agencies working with extension across the basin. We also plan on using the Centers for Ocean Sciences Education Excellence (COSEE) (http://www.coseegreatlakes.net/) which has a Great Lakes component. They have many resources for active researchers to effectively communicate their research findings within outreach activities. They even organize a course for teachers on the Lake Guardian. We will provide them with updated information for their lesson plans as well as provide them with educational material from our experiences on the Guardian.

Finally, we have two possibilities in the planning stages. First, a large venue for outreach will be the Tall Ships Challenge Great Lakes 2013 (http://www.sailtraining.org/tallships/2013greatlakes/). Several Great Lakes ports (e.g. Cleveland and Chicago) will host events during the summer of 2013. This series will celebrate the 200th anniversary of the major military events of the War of 1812 but is also dedicated to promoting awareness of the Great Lakes' ecosystems and fresh water conservation. Thousands of people attend these events to see tall ships but would also be interested in viewing an active research ship. The Lake Guardian could potentially fit one such event within its summer sampling schedule. Our scientific staff could be on the adjacent dock with posters available to discuss Great Lakes ecosystems and GLNPO's monitoring mission. Several tall ships offer tours but opening the Guardian to that level of crowd would be impractical. Second, the Chautauqua Institution (http://www.ciweb.org/) in western New York has a nine-week summer program that annually hosts more than 170,000 visitors from across the nation. Weekly themes generally rotate through topics of politics, economics, religion, and natural history. This year they hosted a theme "Water Matters" that had only talks concerning marine ecosystems. We propose organizing a theme around recent changes in Great Lake ecosystems during a week during a summer between 2013 and 2017. We have contacts with program organizers and could

include talks by the project PIs as well as other experts from the Great Lakes Basin. The site on Chautauqua Lake between Lake Ontario and Lake Erie is a perfect location for outreach on Great Lakes issues.

c. Detailed Budget Narrative

Cornell University

Personnel: All salaries include an estimated [redacted] annual salary escalation effective July 1st of each year, except as noted below for Graduate Research Assistantships.

Senior Personnel: Funds are requested to cover salary for the project PI, Professor [redacted] for one month ([redacted] based on a 9-month appointment) during each year of the grant. He will provide project leadership, oversight, and ensure that all project reports are submitted to the sponsor. The PI will also advise the graduate students. Professor [redacted] holds a nine-month appointment at Cornell University at a current rate of [redacted] The total cost for salary will be [redacted] for five years.

Research Associate: A Research Associate will be employed on the project at [redacted] for all five years of the project. The estimated salary will be [redacted] in the first year. The total cost for salary will be [redacted] for five years.

Research Support Specialist: A Research Support Specialist will be employed on the project for all five years of the project. Two months per year [redacted] for years one and two and five; one month per year [redacted] in years three and four. The annual salary is [redacted] in the first year. The total cost for salary will be [redacted] for five years.

Technicians: Two full time technicians for sample collection and processing. One technician will be entry Technician I level and the other a higher Technician II level. They will be [redacted] for the five year project. The total cost for salary will be [redacted] for five years.

Graduate Research Assistantship (GRA): Two twelve-month (calendar year) graduate research assistantships are requested that include a monthly stipend, tuition and health insurance. There will be one GRA for each of Projects 1 and 2 starting in the spring of 2013. GRA stipends are escalated [redacted] annually, GRA insurance is escalated [redacted] annually. The total cost for two GRA's will be [redacted] for five years.

Undergraduate Students: Two undergraduate summer student interns at the Cornell Biological Field Station. It is estimated they will work full time eleven weeks per summer. The totals cost for two undergraduate students will be [redacted] for five years.

Fringe Benefits: Cornell University federal fringe benefit rate is [redacted] of salary and wages through June 30, 2013 and estimated at [redacted] hereafter. There are no fringe benefit expenses on graduate or undergraduate students. Fringe benefits included, but are not limited to the cost of leave, employee insurance, pensions and unemployment benefit plans.

Equipment: Funds are requested to purchase a Turner Designs 10-AU bench-top fluorometer, (Turner Designs Inc., Sunnyvale, CA). Estimated price in August 2012 is $14,500 plus shipping and handling. We request $15,000.

Travel: A van trip will be necessary to transport five science crew and supplies from Bridgeport, New York to Milwaukee, WI to meet the Lake Guardian (1530 miles round trip for drop off). Crew will be

offloaded in Detroit, Cleveland, or Ft Niagara, New York depending on the ship's route (up to 800 miles round trip for pick up). The total mileage will be approximately 2500 miles per trip. Per Diem is $97 for lodging and $61 for food for a total of $158 per person per day (Milwaukee rates). The five science crew will need one travel day of per diem per trip and the van will be driven round trip to the drop off and pick up locations by a sixth staff member who will need two travel days of per diem per trip. It is 785 miles to Wisconsin one way. It will take ~13 hours each way. The 400 miles from drop off will be ~7 hours each way. The total days of per diem will be 7 days per trip. There will be two trips per year in April and August. Food and lodging while on the ship will be provided by EPA. In summary, per year we expect travel to and from the boat will be approximately $2775 for mileage (2500 miles at $0.555 per mile for two trips) and approximately $2212 for per diem (7 days at $158 per day for two trips) for a total of approximately $5000.

In addition, we foresee the necessity for two members of our group to travel within New York State between lab groups in Syracuse and Buffalo (150 miles one way) five times a year for a total of 1,500 miles ($825) and ten per diem days (Syracuse per diem rates $77 lodging and $46 for food) for a total cost of $2,000.

We also plan on two members of our group attending annual meetings (IAGLR or other) to give presentations at a total cost of $4,000 and one member attending the annual Lake Committee meeting. Using Ann Arbor, Michigan as a midpoint distance (500 miles one way from Syracuse), and the cost would be $500 for transport and three days of per diem ($90 lodging, $56 food) for a total near $1,000.

Travel to present data for stakeholders and for meetings associated with CSMI planning around the Great Lakes can only be estimated. We expect this may be in the order of $4500 per year.

Total travel expected for year 1 is $2,500 less due to only one sampling occasion in April 2013. Total travel is therefore estimated to $14,000 for year 1 and 16,995 for year 2 to 5 with an escalation rate of 3% each year.

Materials and Supplies: Include field sampling supplies (nets, flow meters, filtering manifolds, additional counting station in year 1 with microscope, computerized tablet and computer, wildlife computer's light meter (MK-9, 2 units, $3000), lab supplies, software and updates, computer supplies, and communications. Included is an escalation rate of 3% each year on supplies starting in year 2.

Other: Funds are requested for stable isotopes and qPCR analysis for Project 2 estimated to $4000 per year with 3% escalation each year starting in year two.

Subcontract with Buffalo State College: Total Project Cost: The total estimated cost for the BSC part of the proposal for five years is $1,094,726.

Buffalo State College will be a collaborating with Cornell University as a subcontract on this proposal. Karatayev and Burlakova will be responsible for all aspects of benthic and the major part of the AIS study (Project 3, Invasive species detection) and the bioindicator study (Project 4, Compare existing and develop new benthic community biological indices for macroinvertebrate bioassessment). Burlakova will be also responsible for the grant management at Buffalo State College. Together with their technician and a graduate student, they will collect samples (including 2 people on board Lake Guardian during benthic sampling cruises), and perform samples sorting and identification. The total number of samples is predicted to be around 240 per year. [redacted] and [redacted] will be responsible for analyses and interpretation of data, report and manuscript writing, and will supervise the graduate student.

Indirect Cost: F&A (indirect) costs have been proposed at a rate of [redacted] of Modified Total Direct Costs (MTDC) through June 30, 2013 with an escalation to [redacted] on July 1, 2013 as approved in Cornell's rate agreement with the Department of Health and Human Services. MTDC exclusions include capital equipment, GRA tuition and health insurance, and subcontract costs in excess of [redacted] per subcontract.

Cornell University Budget	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Personnel						
Senior Scientist	[redacted]					
Research Associate 12 months						
Research Support Specialist 1-2 months						
Technicians (24 months)						
Graduate Student Proj 1						
Graduate Student Proj 2						
Graduate Tuition and Insurance						
Summer interns						
TOTAL PERSONNEL						
Fringe Benefits						
Fringe benefits ([redacted] to 7/31/2013, [redacted] thereafter)	[redacted]					
Travel						
In State travel for Research Meetings	2,000	2,060	2,122	2,185	2,251	10,617
Out of State (WI, MI, IL, IN, OH, MN for sampling	2,500	5,150	5,305	5,464	5,628	24,047
Out of State (WI, MI, IL, IN OH, MN) for meetings and extension	9,500	9,785	10,079	10,381	10,692	50,437
TOTAL TRAVEL	14,000	16,995	17,505	18,030	18,571	85,101
Equipment	15,000					15,000
Supplies	15,000	3,090	3,183	3,278	3,376	27,927
Contractual						
Buffalo State College	[redacted]					
Other						
Stable isotopes and qPCR	4,000	4,120	4,244	4,371	4,502	21,237
Total Direct Costs	543,990	594,244	608,047	589,741	586,629	2,922,650
Full Indirect Costs ([redacted] & [redacted])	[redacted]					
Total Project Costs	**736,646**	**779,068**	**794,871**	**782,536**	**774,405**	**3,867,525**

Buffalo State College

Personnel Salaries: The salaries include monthly salary for Senior Scientist (that has soft money position, and generate her support from grant funding (7 months per year, total), one technician (12 month a year, total , and one graduate student per year, Years 2 and 3, total), and undergraduate students (all years, , total

Fringe Benefits: Buffalo State College fringe rates as negotiated by Research Foundation of SUNY and Buffalo State College: Regular Benefits in Yrs. 1-5, Benefits for graduate students in year 2 and in year 3; Benefits for undergraduate students in years 1-5. Total Benefits:

Travel: will include gas, lodging and meals (total $39,285).

Supplies: will include field sampling supplies and lab supplies, software and updates, computer supplies, and communications (total $20,113).

Contractual: Taxonomic Consulting on selected benthic groups (Oligochaeta and Chironomidae) (e.g., taxonomic experts Heidelberg University, and University of Windsor), total $49,731.

Indirect Cost: Research Foundation of SUNY/Buffalo State College has a federally negotiated (DHHS) indirect cost rate for research at using Modified Total Direct Cost base, total

Total Project Cost: The total estimated cost for the BSC part of the proposal for 5 years is **$1,094,726**.

Buffalo State Subcontract

Budget	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Senior scientist Technician Graduate student Undergraduate students Fringe benefit for scientist and technician (of salary) Fringe benefit for graduate student ( ) Fringe benefit for undergraduate students ( ) Travel (NY,IL, WI, MI, OH, MN)						
Supplies	$3,640	$3,822	$4,013	$4,214	$4,424	**$20,113**
Consulting						
Indirect cost (of direct cost)						
Total cost	**$186,341**	**$232,623**	**$242,191**	**$212,356**	**$221,216**	**$1,094,726**

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